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EDITORIALS.

SOME ASPECTS OF SCIENTIFIC RESEARCH IN RELATION TO THE GLASS INDUSTRY.[1]

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Although one of the most ancient of the chemical industries, the manufacture of glass, like most of the other ceramic industries, has been one of the last to feel the influence of modern science. This is, of course, due largely to the fact that the industry, being older than the science, had necessarily to develop along purely empirical lines. The rule of thumb methods, and their accompanying "trade secrets," which characterize the development of a complex industry by this method naturally bred a conservatism of view-point which did not easily appreciate the value of scientific research or the advantages of scientific control over the materials and the processes of the industry. Furthermore, it must be admitted that until comparatively recent times the chemistry and physics of high temperatures, such as those prevailing in the most important processes of this industry, were so little developed that the science was scarcely itself in a position to render important service to the industry, such a service for example, as organic chemistry has rendered to the synthetic dye industry which is a typical example of a great industry built upon a highly

[1] Address before the American Ceramic Society meeting held at the Fifth National Exposition of Chemical Industries, Chicago, Ill., September 24, 1919.

developed scientific foundation and completely under the control of scientific methods and the results of continuous research.

During the last quarter of a century, however, there has been a gradual change in this situation with respect to the glass industry. With the development of methods of producing, controlling and measuring high temperatures in the laboratory our knowledge of the chemistry and physics of high-temperature processes has gradually and steadily increased. With the expansion of our knowledge in this field have naturally come opportunities to apply its methods, laws and data to the solution of industrial problems. The more enterprising glass manufacturers began to employ chemists in their plants and in laboratories which they installed. Starting initially as a works laboratory, sometimes illy equipped and miserably housed, they busied themselves at first almost entirely with control problems and works' troubles. After they began to demonstrate their usefulness, their opportunities, responsibilities and resources both in men and equipment naturally increased and the beginnings of real research laboratories in connection with the glass industry appeared.

Then came the great war and America awoke to the realization that she must rely solely upon her own resources for the manufacture of all the different kinds of glass which she required. One of the first results of this situation was the quantity production of a grade of chemical glassware, the equal and in some respects the superior of that for which we had previously been dependent upon Germany. This new American glass is essentially a product of scientific research and was developed by men trained in the principles of modern chemistry and physics and having the necessary laboratory facilities at their disposal.

Then came America's entrance into the war and with it the realization that we should need hundreds of tons and numerous varieties of optical glass, that is, glass conforming to the most rigid specifications, as to color, transparency, homogeneity, and freedom from striations, bubbles, stones or other imperfections which might interfere with vision; and on top of these qualifications each of the various types required had to have a definite and rigorously fixed index of refraction and coefficient of constringence. The extent to which the glass in an officer's binoculars, or the glass in a gunner's range-finder, or the glass in a submarine or trench periscope, met or failed to meet these rigid specifications would probably be measured in terms of human lives. The situation which existed in this country with respect to optical glass, at the time America entered the war, was thus a real crisis. It is not my purpose to tell you the story of how this crisis was met. This will be ably done by others on today's program who are competent to speak from first-hand knowledge of the problems met and solved. Suffice to say that the crisis *was* met and the problems which *had to be solved were solved* and their solution brought about a degree of coöperation between the practical man of the factory and the scientist of the laboratory which would probably have required many years to bring about without the stimulus of war. With this coöperation there naturally developed a mutual respect, understanding and appreciation on both sides which should mean much for the future of the glass industry in this country.

If today we put to the glass industry of America the question, "Do you know how to carry out the multifold operations necessary in order to produce good chemical-glassware, good optical glass, good plate glass, good X-ray bulbs, good incandescent bulbs, etc.?" the industry can truthfully answer, "Yes." Also, if we put the question, "Do you know how to do it efficiently?" the industry can still in many respects truthfully answer, "Yes," although in some cases, perhaps, in a rather weak voice. But if we put the question, "Do you know why you do thus and so, and do you know what happens at this or that stage of the process?" the industry must in the majority of cases reply, "We do not know."

Now, it is not enough to know *how*, we must also know *why*. For quality of product, it is perhaps sufficient merely to know how, but for efficiency, safety and confidence as well as for progress it is also necessary to know why. No industry which merely knows *how* is in a healthy condition. The feeling of confidence which comes with knowing the why of every step in the manufacturing process carries with it certainty of control, progressive lowering of costs, enhanced protection of the workmen, progress in the development of new and improved products, and a degree of insurance against such evils as might otherwise attend the exhaustion or temporary scarcity of certain raw materials, fuels, machinery or other necessary supplies.

In the face of the imperative demands of war, or of the almost unlimited markets created by the destruction wrought by war, the necessity of operating with the greatest efficiency is not felt by an industry as it is in normal times with close competition and a market whose further expansion is dependent primarily upon lower selling prices. This is well illustrated in the case of the first two glass factories to resume production after the evacuation of Belgium by the Germans. These two factories, which I had the opportunity to visit last summer, are located in the same district and, therefore, subject to the same conditions regarding fuel, common labor and costs of materials. They are both engaged in the manufacture of window glass, for which, for some time to come, there will be an enormous demand for reconstruction in the deva-tated regions. In the first factory the glass is manufactured by the older process in which the "metal" is gathered directly from the furnace on the end of the blower's pipe and then blown into a long cylinder which is cut lengthwise, transferred to the flattening furnace and there flattened into a sheet by a second workman. In this factory the blowers are paid from $250.00 to $300.00 per month. In the second factory, operating under the Fourcault patents, the process is entirely mechanical, no labor, other than that employed in firing, being employed between the point at which the "batch" is shoveled into the tank furnace and the point at which the completed panes of glass issue from the furnace. The highest-paid workman in this plant received about 18 cents per hour. In spite of the apparently great difference in efficiency and in costs of the two methods of operation they were nevertheless both able to operate at a profit in a market where demand and not manufacturing costs is the principal element in determining the price of the product.

In the laboratories associated with an industry the work to be done may perhaps be roughly classified under three headings: First, *routine testing* of raw materials and products and similar work having to do with the control of the operation of the factory. Second, *works problems*, that is the solution of problems whose immediate purpose is the cure of some source of trouble in the works or the improvement of some part of the process or product. Third, *fundamental research*, that is, research whose primary purpose is to find out the why of some stage of the operation, or to secure quantitative scientific data concerning the materials used, the processes occurring and the product obtained both in its completed state and in different stages of its manufacture.

It is the importance of the last type of work which I wish to emphasize particularly for it is only by the solution of these more general and fundamental problems that the scientific foundation of an industry can be laid. In the glass industry almost everything still remains to be done in this respect. For example, we know that the relation between the viscosity of the "metal" on the one hand and its temperature and composition on the other is one of the important elements which is associated with the operations, of stirring. gathering, drawing and blowing and yet one searches the literature in vain for any measurements of the viscosity of industrial glasses. The Germans may have secured these data, but if so, they have not published them. During the last two years we have been working on this problem at Illinois and have succeeded in perfecting an apparatus and in determining the viscosity-temperature curves for seven of the more important types of optical glasses.

Similarly, we know in a general way the mathematical theory of the process of fining and know that it is closely connected with the viscosity, with the surface tension and with the vapor pressure of the molten glass, but no measurements of surface tension of industrial glass seem ever to have been made, neither are any data concerning the vapor pressures of glasses at different temperatures or concerning the composition of the vapor available. Not even such a simple property as density seems ever to have been determined in the case of molten industrial glasses. Our knowledge of the reactions which take place in the melt, of the compounds which form, particularly those which crystallize out, and of the conditions under which they crystallize out, is still very fragmentary. Again, we know that soda can be substituted for potash to a large extent in certain optical glasses without impairing the index of refraction, but it is stated that this substitution is impracticable, because of the increased color which accompanies it. We do not know, however, the cause of this increased color, or whether it even is actually and primarily a necessary accompaniment of the use of soda.

There are numerous other examples of troubles for which the cure has been found, but concerning which we know nothing whatever of the true nature of the disease, or why the remedy employed resulted in a cure. It would not be at all surprising to find in some of these instances that the cure was not directly produced by the remedy employed, but resulted from some unrealized variable whose alteration accidentally accompanied the application of the remedy, the supposed remedy itself having nothing at all to do with the matter.

We know scarcely anything concerning the nature of the gases which remain in solution in the glass even after its completion nor do we know what rôle, if any, they play in determining the properties of the glass. It is quite reasonable, for example, to suppose that a method of manufacture which controlled the nature and quantity of these dissolved gases might produce an incandescent lamp bulb having a much longer life than those at present employed, and might place in the hands of the physicist a type of apparatus glass which would be of great value in high-vacuum investigations. The present methods of manufacture, as you know, exert no control whatever over this component of the glass.

The relation between some of the optical properties and the compositions of glasses has been extensively studied, but in the case of many of the other physical properties our knowledge is almost zero or at best only fragmentary. Suppose we desire, for example, to manufacture the most suitable glass for sealing in the lead wires of an incandescent light bulb, what do we know about the laws which govern the relation between the electrical conductivity of a glass and its composition? Almost nothing. I have seen a large Mazda lamp bulb destroyed in less than an hour's use owing to the electrolysis which occurred between the two leading-in wires, resulting in the formation of a layer of bubbles along one wire and a consequent destruction of the vacuum.

The purely scientific questions which present themselves for solution are almost infinite in number:

1. Under what conditions does one get metallic copper and cuprous oxide in a glass and how can one distinguish between them?

2. In a chrome-aventurine glass is the second phase chromic oxide or a chromic silicate?

3. Why does fluoride give a white glass with no red by transmitted light?

4. What compound gives the pink color with manganese?

5. What gives the red color in chrome pink?

These are a few questions which have been recently brought to my attention by an authority on colloid chemistry.

Some of the lengthy discussions which one finds in the literature concerning some of the questions arising in connection with glass manufacture are after all rather futile ones. The famous case of arsenic is an example. Much printer's ink has been employed in discussions as to what happened to the arsenic after it was put into the batch, just what influence it had on the properties of the glass and why it had this influence. Did it remain in the glass as As_2O_3 or was it oxidized as As_2O_5? In the discussion of this latter point, for example, by two such authorities as Dr. Hovestadt and Dr. Rosenhain, we find one of them claiming that if an oxidizing material is employed in the batch the arsenic remains in the glass as an arsenate, while if no oxidizing agent is employed no oxidation of the arsenic can occur and it is all driven out in the vapor. The other believed that since arsenic acid is easily reduced by heat alone any arsenic remaining in the glass was present as As_2O_3, and since arsenic acid was a weak acid it could hardly remain in combination with the alkalies and, therefore, its presence in the glass would result in the formation of insoluble impurities and a consequent opalescence. Now all of this discussion concerning the rôle of arsenic and its amount or condition in the finished glass has been a needless one, in so far as the questions raised were worthy of solution, because the problem under discussion was one which the resources of chemistry have long been in a position to definitely solve, if any one had taken the trouble to carry out the necessary experiments as has in fact been recently done.

There is thus no lack of chemical and physical problems in connection with the glass industry whose solution requires only the painstaking work of trained investigators. It is not enough, however, to merely point out the great need of fundamental research in this field; it is necessary that definite steps be taken to prosecute this research as vigorously as possible. Now there are three types of laboratories in which research of this nature might be carried out. First, the research laboratories of the industry itself. These laboratories while as yet few in number may be expected to grow both in number, equipment and personnel and a portion of their resources should be devoted to some of the more fundamental problems common to the industry as a whole, as a part of their contribution to the general advancement of those branches of the physics and chemistry underlying the industry. Second, the government laboratories and the laboratories of research foundations, such as the Geophysical Laboratory. These may be expected to continue their work along these lines and should receive the support of the industry in their efforts to extend their facilities for such work. Third, the laboratories of the ceramic departments of the universities. Now, although we have some half-dozen departments of ceramics in the country at the present time, these departments have grown up around and been fostered by the clay industries and have as a natural result confined most of their activities in the past to these branches of ceramics. There exists nowhere in the United States a single professorship of glass technology. The endowment of such professorships by the industry would do much toward stimulating research in this field in our universities and in attracting young men to the study of this subject. And when all is said, it is, after all, the scarcity of trained men which is at the present time the greatest impediment to the more vigorous prosecution of research in this field. The Board of Advisors of the Department of Ceramic Engineering at the University of Illinois appreciated this situation and at its meeting in 1915 voted to recommend to the trustees that such a professorship be established by the University. Before any action could be taken, however, the disruption consequent upon our entrance into the war made it necessary to postpone the consideration of any expansion in the work of the Department and at the present time the financial situation at the University is such that any expansion in its activities is out of the question. The universities of the country with but few exceptions have been unable to make any general increase in the salaries of their teaching staffs to meet the increased cost of living during the past four or five years and until they are in a position to correct the present desperate condition in which they find themselves, owing to the continued resignation of teachers of technical subjects, any plans looking towards expansion of activities by the creation of additional professorships could scarcely be justified.

I believe that no one of the institutions at which a department of ceramics exists is financially able at the present time to expand its activities. In fact, most of them have had to contract their activities and to struggle along with a reduced staff and smaller resources than they had before the war. If the glass industry is desirous of securing the coöperation of university laboratories in training additional men for the industry, and in helping to solve some of the fundamental problems in this field, some way of providing the needed financial assistance must be found.

The industry cannot afford to have the source of supply of its future technical staffs dry up and that is just what is occurring. A steady stream of requests for technically trained men for the glass industry and the other ceramic industries comes to my desk throughout the year. More and more of these requests are for men with graduate training, that is, men trained to do research. These men are not being produced. Few, if any, of our Ceramic departments are at the present time in a position to properly train such men for the glass industry. Such training is the most expensive which a university gives. Adequate fellowship funds are needed to enable the men to complete the course of training required to produce a research worker. Where six years ago a fellowship of four or five hundred dollars would pay a student's living expenses, today double that amount is required.

In the past the industrial world was content to rely entirely upon the universities for the advancement of science, but today there are many signs that scientific leadership is passing from the hands of the university to the hands of the great industrial research laboratories and the privately endowed research foundations. Scientific research is becoming more and more costly and the universities as organized at present can no longer compete on terms of equality with the efficiently organized and adequately financed industrial and endowed research laboratories.

Thus, although no longer entirely dependent upon the universities for scientific research, the industrial world is and must continue to be entirely dependent upon them for the training of its technical personnel, and a part of the responsibility for seeing that such training is provided must in the future be accepted by the industries. Although the Sherman law forbids the formation of combinations in restraint of trade, there is, I believe, nothing in that Act which forbids the formation of combinations within an industry for the purpose of uniting on a program for furthering research on fundamental problems and for aiding the universities of the country in the work of training the technical personnel required by the industry.

SUPERIOR REFRACTORIES.[1]

By Ross C. Purdy.

This is a plea to the American Ceramic Society to initiate directly, or through the agency of the National Research Council, active and thorough researches of our refractory problems by a Federal bureau. This recommendation is made in spite of a keen appreciation of the excellent work which has already been completed and at present being undertaken by the Federal Bureaus, the National Research Council, the American Ceramic Society, the Refractories Association, the American Society for Testing Materials and other organizations. Much has been done by our universities and much by industrial concerns. In the presentation of this plea there is no forgetting of the advances we have made through the efforts of these several agencies and there is no thought but that these several bureaus, societies, universities and industrial concerns should continue independent researches

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on refractories as has been their wont, and as they no doubt are continuing, for there are advantages in independent investigations by several organizations each with its peculiar purposes, viewpoints, facilities, etc. Indeed, we want more of this dispersion of interest and activity in researches on refractories. It would be well if each of the several bureaus, societies, colleges, etc., would see the great need there is for progressive and aggressive investigations of our refractory problems and each independently initiate and prosecute researches in this the one branch of Ceramics in which we are the most backward in meeting the industrial demands for a better product.

Notwithstanding this keen appreciation of the benefits derived from independent investigations and researches by several, we must recognize the advantages of unrestricted facilities, not alone in expensive and varied equipment to meet every desired requirement, but also in facilities for very accurate observations and to the obtaining of trustworthy constants such as can be obtained only with highly trained investigators and expensive apparatus. We must appreciate also facilities for broad observations, not alone in the development and manufacture of refractories, but also as to the industrial needs for refractories. It is very obvious that the most rapid and the most certain progress in the development of refractories can be had only by an elaborate and aggressive investigation, an investigation that is beyond the possibilities if not beyond the scope of independent organizations of small financial resources and limited interest.

Then, too, the benefits would not be alone to the manufacturers of refractories, indeed not as much to them as to the users, and to the national and world-wide welfare. It does not require much breadth of thought to realize how dependent is our present-day industrial progress on the development and manufacture of superior refractories, refractories that are superior for the several purposes to those now being used. Consider for a moment the saving of time and of labor and of metal that is effected by the closed electric furnace over the open-top crucible for brass melting. Electric furnaces today are melting less than one per cent of the brass used and yet they are saving a million dollars' worth of zinc metal by reducing its loss from 6 to 9 per cent down to one per cent and less. In this one operation alone they are not only saving metal but also labor, and at the same time are making the operation more tolerable for the operators. Examples could be multiplied by reference to the many heat-treating operations where with development of new equipment and processes they are effecting economies and bettering operating conditions. But these benefits cannot be fully realized until more suitable refractories are developed. The rapid development and adoption of electric furnaces for a large number of purposes has given rise to an urgent appeal for better refractories. The development and rate of adoption of the electric furnace has been phenomenal but is greatly retarded by want of suitable refractories.

There is an urgent need today for an understanding of the qualities or properties that are wanted in each of the large number of industrial requirements. This is no small task. It involves accurate observations and study of possible variations in operation control in the place and under the conditions that refractories are used. It requires a knowledge of metallurgy and of ceramics and above all it requires an appreciation of the relation of costs to service. The most suitable refractory will at the best be a compromise, not alone because of the antagonistic properties that are required, but also because of the economics of service involved. An adequate and worth-while industrial survey and research of refractory requirements is so far beyond the possibility and scope of individual organizations, and the benefits derived are so broad, affecting the cost and pleasure of living of every citizen, that it should be made under the auspices of a Federal Bureau where the expense is borne by general taxation.

If a discussion of the political economics involved were needed, it could be shown that since our national welfare is more and more dependent on industries as compared to agriculture, and since the farm and the industries are today more mutually dependent than at any previous time, all citizens should share in meeting these costs. And if the economic considerations were carried farther, it would be plain that efficiency, relating to time and money expended as balanced against the value of results obtained, would require the employment of the broadest-trained investigators, the most accurate and efficient equipment, and the most liberal opportunities, all of which are possible only under Federal auspices.

Then, too, there should be extensive research of material resources and manufacturing processes. This should parallel the industrial survey. The two should be closely associated and each be given liberal support. A Federal bureau would secure for this a far better coöperation of the independent organizations than could any other agency, a coöperation that is very essential.

A great deal of progress has been made in the last two decades, not alone in refractories themselves, but also in our appreciation of the relative value of the chemical and physical means of judging their suitability. We no longer hear of the mistaken and much over-emphasized importance of chemical analyses of clays. We have not, and probably never will, discard the chemical analysis as being without value. It has a value, for it does give information, but we certainly have less faith today in the empirical methods of Bischof, Seger and Ludwig for estimating the refractoriness of clay from the chemical analysis. We have learned, too, that clays having the same chemical analysis but differing in physical and mineral character may have different values for refractory purposes. Indeed, it is not uncommon that a freshly mined clay would have but small value for use in refractories but will be made an excellent clay by merely weathering. This is an instance of the importance of texture and structural strength, factors that are not disclosed by chemical analysis.

We are appreciating more and more that the success of a clay for refractories is as largely dependent upon the physical properties that make it adaptable for manufacturing processes, as it is on its chemical and mineral composition. Indeed, the fact is slowly being appreciated that behavior of a clay in the usual fusion test is dependent on physical properties as well as on its chemical composition. No method yet devised can be substituted for the direct fusion test.

Decided progress has certainly been made in knowledge of the method of study, and progress has also been made in knowledge of what is essential in refractories, but we have made but little in the actual production for specific purposes.

It is not the purpose here to elaborate upon the relative values of the several methods of studying refractory materials and wares or how to produce desired properties in the finished ware. We are making fair progress in these.

What we need today is the development of refractories that will remain practically constant in their physical and chemical characteristics through the maximum heat treatment to which they will be subjected when in use. We recognize that when a clay is burned in a fire-brick kiln the melting together of its mineral constituents is but partly progressed and that further reactions and solution will take place when the clay is subjected to more severe heat treatment. We also recognize the importance of such factors as time, oxidation, etc., in the progress of clay fusion. It is well known that clays that appear equal in the fusion test will differ in load-carrying capacities when subjected to heat treatments much less severe than those required to cause them to deform in the fusion test, and we recognize this as one indication that suitability of a clay refractory is not wholly dependent upon its ultimate fusibility, but in fact is more dependent upon its rate of fusion.

From the evidence that is already before us it is apparent that, for the most severe heat requirements, the refractory must have had its physical and chemical properties developed to their maximum; far beyond the possibility of alteration in any heat treatment to which they will be subjected in use.

If fused bauxite, fused alumina, sintered magnesia, or silicon carbide would meet all the industrial high-temperature requirements, there would be no need for this plea for Federal research on refractories. There are needs which these materials will not satisfy and for which materials, such as the spinels, sillimanite, zirconia, etc., are better suited. We have heard much of the possibilities of zirconia as a refractory and have had several industrial trials of refractories made of zirconia, but we know little aside from the fact that we cannot yet produce a zirconia refractory that is economically possible. The same is true of sillimanite, a most excellent refractory of exceptionally low electrical conductivity.

The value of these fused refractory-oxides lies, not alone in their extreme refractoriness, but also in their constancy in volume, capacity to withstand sudden temperature change, resistance to chemical and slag reactions and ease with which a desired texture can be produced. Refractory articles from these materials average much higher in desired or required properties than any of the partially fused or partially sintered refractories. No refractory will carry load at high temperatures and withstand the destructive abrasive, slagging and temperature changes as will fused bauxite, silicon carbide or sintered magnesia. These same superior values might be found with other materials which have been previously fused.

The great problem with these materials, however, is their production at a cost compatible with the service they will give. The solution of this problem is not easy and certainly deserves the serious attention of a Federal bureau with extensive capacity to conduct investigations in the laboratory and field.

The plea that is being presented is that the American Ceramic Society initiate and secure coöperation by the several other Societies in a request for aggressive researches by some Federal Bureau in the development and economic promotion of refractories. This will include a definition of the possibilities of clay refractories; an improvement in such as the silica and magnesite refractories; but such a research should especially develop and define the most economic methods of production and use of such superior refractories as can be made of zirconia, the spinels, sillimanite, the nitrides, etc. This is no small program. It will tax even a Federal Bureau, if executed with the vigor that the present urgent industrial demands fully warrant.

This plea is respectfully submitted to the Standing Committee on Research for their careful consideration.

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